# REPORT OF THE INDUSTRIAL ENGINEERING TOUR AT THE FEDERAL TELECOMMUNICATION LABORATORIES, NUTLEY, NEW JERSEY

Frank G. Vessell

Letter on front cover:

REPORT OF THE INDUSTRIAL ENGINEERING TOUR AT THE FEDERAL TELECOMMUNICATION LABORATORIES, NUTLEY, NEW JERSEY

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USN

RATORIES

during period

2 January 1952 to 29 March 1952

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# I INTRODUCTION

## A. Nature of Assignment

In connection with the Naval Postgraduate School Engineering Electronics Curriculum, a student spends approximately thirteen weeks at some design laboratory in order to derive industrial experience.

This report covers the period 2 January 1952 to 29 March 1952 which was spent at the Federal Telecommunication Laboratories, Nutley, New Jersey in fulfillment of the above requirements.

## B. Specific Problem

In one system undergoing development, a pre-amplifier is required at a location remote from the main amplifier and connected to it with a 100 ohm coaxial cable.

The pre-amplifier is required to match the output impedance of a crystal detector whose approximate internal impedance is 840 ohms; however since power transfer is not necessarily a critical factor, the design of the pre-amplifier actually requires that some gain is realized if possible and that the output impedance match the 100 ohm coaxial cable within reasonable limits.

An electron tube pre-amplifier requires that a fairly large amount of power, necessary to heat the filaments and to provide the plate bias, be transported from the generators to the remote location. An additional problem with electron tubes is that they are susceptible to microphonics. This is an important problem since the pre-amplifier is likely to be subjected to excessive vibration.

It would be desirous to replace the electron tube pre-amplifier with one which has very low power requirements, which is not subject to

microphonics, which is small in size, and which would provide the necessary gain and impedance match to the 100 ohm cable.

C. Method of Approach

It was decided that an investigation should be made to determine the feasibility of using transistors in the pre-amplifier. The desired characteristics of the transistor pre-amplifier are as follows:

1. Output impedance to match 100 ohm coaxial cable.
2. In order to get as large a voltage transfer as possible, the input impedance to the pre-amplifier should be high.
3. A 10 db. over-all gain is desired; however impedance matching to the 100 ohm coaxial cable is more important, but a compromise between gain and impedance match could be tolerated.
4. Pulse transformers were to be avoided if at all possible.
5. The amplifier must pass a pulse of short duration without distortion.

Keeping the above requirements in mind it was necessary to investigate the following characteristics of available transistors to determine their suitability for use in the desired circuit:

1. Static and dynamic characteristics
2. Uniformity of transistors
3. Behavior with temperature
4. Stability characteristics
5. Circuit configuration for desired performance.

Previous work done by laboratory personnel provided some of the answers to the above for the General Electric Type G11 transistor.

## II LABORATORY INVESTIGATION

### A. Study Phase

Appropriate literature on transistors was studied. A bibliography is given in Appendix I.

### B. Experimental Work

In order to obtain characteristics of the transistors a circuit whose schematic diagram is shown in Figure 1 was built by one of the laboratory technicians. Slight changes had to be made in the circuit for testing different transistors due to the fact that maximum current and dissipation requirements are different for the Bell Telephone Laboratories transistors from those for the General Electric transistors. A search of the literature indicated that the dynamic characteristics of the point contact type transistors were practically identical with the static characteristics, and therefore only static characteristic were measured.

Approximately 50 Type G11 General Electric transistors were available. These were the point contact germanium transistors with maximum emitter and collector current ratings of one and two milliamperes respectively. The circuit of the tester had to be modified as indicated in Figure 1 to prevent excessive current. During the tests on the type G11 transistors it was noted that when the hand or a warm soldering iron were brought near the transistor, the characteristics changed rapidly.

Figures 2, 3, and 4 show the static characteristic for two G11 transistors tested.

Three Bell Telephone Laboratories type 1729 transistors were available for test. The static characteristics of two type 1729 transistors are plotted in Figures 5, 6, and 7. No pronounced change was noted in

characteristics when the hand or a warm soldering iron were brought momentarily near the transistor.

One type 1729 transistor was tested at temperatures from -47°C to +90°C. The results of the static characteristics test are shown in Figures 8, 9, and 10.

Current literature on the point contact type transistor indicated that probably the most suitable type of amplifier for the desired performance was the grounded collector configuration. Figure 11 gives the circuit symbol for the transistor, one equivalent circuit representation, and the general four-terminal active network and its equivalent circuit giving the equations and various parameters of the network. Figure 12 gives the synopsis of the grounded collector transistor amplifier, and Figure 13 show the circuit that was built for testing the performance of the amplifier. Components were made adjustable in order that the operating point and A-C impedances could be varied during the test. Applying the equations of Figure 12 to the circuit of Figure 13 indicates that the following performance can be expected:

| $R_2$ ohms | $R_L$ ohms | Input Impedance ohms | Output Impedance ohms |
|---|---|---|---|
| 0 | 400 | -408 | -800 |
| 0 | 20K | 12K | -800 |
| 0 | 12K | 19.7K | -800 |
| 5K | 400 | 3.7K | -200 |
| 12K | 400 | 7.3K | 100 |
| 5K | 900 | 3.3K | -300 |
| 12K | 900 | 7.1K | 100 |

The equivalent circuit parameters used in the equations of Figure 12 were obtained from the static characteristics in the manner shown in Figure 14.

The grounded-collector amplifier was tested for performance by feeding into it the output of a crystal diode mounted on an electromagnetic horn. A two microsecond radio frequency pulse was fed to a probe placed in front of the horn assembly. The crystal was biased in the forward direction with a current of 15 micro-amperes to provide more uniform impedance characteristics. The various circuit parameters were varied as indicated in Figure 17 and input impedance, input voltage, output voltage, and rise time were measured. During the entire test the crystal bias was kept constant at 15 micro-amperes, and the collector and emitter currents were maintained constant, at 4.3 and 0.7 milliamperes, respectively. The negative input pulse was kept at a width of two micro seconds.

In all cases the input and output voltages were measured by using a Tektronic oscilloscope, and input impedance was, likewise, measured with the scope. The trace of the input pulse was first adjusted on the oscilloscope to a convenient size. The output from the crystal diode was then connected directly to the scope in parallel with a variable resistor whose value was adjusted until the pattern on the scope had the same amplitude as that of the input voltage. The value of the resistor was then equal to the input impedance.

It is to be noted that when the output of the crystal was connected directly to the scope the bias current was removed; however investigation proved the error in measuring input impedance was small.

A type 1768 Bell Telephone Laboratories transistor (switching type) was tried in the amplifier, out of curiosity, but it had a definite tendency

to oscillate and the output voltage was approximately one-half that of the type 1729 transistor. Since the transistor is designed for switching purposes, it was not intended it be used in the pre-amplifier.

The tests indicated that the grounded-collector stage might be used as the first stage of the pre-amplifier, followed by a grounded-base amplifier to get voltage gain, and followed by a final grounded-collector stage for matching to the coaxial cable.

The data shown in Figure 16 tends to indicate that a grounded-collector amplifier with same resistance added in the collector lead would be suitable for feeding a 100 ohm cable or a grounded base stage.

The grounded-base stage shown in Figure 15 was connected to the previously tested amplifier and the same measurements were taken. However, it was discovered that the input impedance was lower than it had been for the grounded-collector stage alone and also the output voltage was less.

Since the previous tests indicated that the first stage should be able to adequately drive a grounded-base stage of about 200 ohms input impedance, the second stage was disconnected and a partial re-run was made on the grounded-collector amplifier. The re-run indicated an entirely different set of input impedance values. In the process of re-checking the performance of the amplifier the remaining two type 1729 transistors were burned out; therefore the discrepancies between the two sets of values for the input impedance could not be definitely resolved. Additional data should be obtained using new transistors.

A General Electric type G11 transistor was then tried in the grounded-collector circuit and the result of the tests is shown in Figure 17.

Several transistors had to be tried before one was found that was fairly stable, and even then the operating point had to be varied until a stable area was found; however, within a limited range, the performance of the selected transistor was similar to that of the Bell Laboratories type 1729.

## III CONCLUSIONS

### A. General Electric Type G11 Transistor

The static characteristics of the type G11 transistors vary so markedly from unit to unit that it is hard to realize that it is the same type transistor. Figures 2, 3, and 4 show vividly that there is very little, if any, similarity between the static characteristics of two transistors. Although complete curves were run on only two transistors, previous experience by other experimenters in the laboratory indicate a definite lack of uniformity in type G11 transistors.

When subjected to comparatively minor temperature changes, the static characteristics vary rather rapidly. No complete temperature tests were run on this type transistor because the Type 1729 Bell Laboratories transistor proved so superior in this respect.

Stability characteristics leave much to be desired, although the transistor seems to be well suited for use in oscillator circuits where the inherent instability is desired.

For use in amplifier circuits, the limited tests performed indicate that the circuit must be "tailor made" for each particular transistor.

### B. Bell Laboratories Type 1729 Transistor

Static characteristic curves for two transistors, shown in Figures 5, 6, and 7, indicate that the variation between transistors is less than, or in

any case, not greater than, the variation in characteristics of electron tubes.

The transistor was stable in an amplifier circuit except when a large resistance in the base circuit was not compensated by a high load resistance and a resistance in the collector circuit. It appears very probable that in a given circuit a transistor could be replaced by another similar type with a very good chance of the circuit performing properly. In the circuit tested, all three transistors gave approximately the same performance. There was no tendency for the amplifier to break into oscillation during rapid switching or slight change of operating point.

In contrast with the sensitivity to temperature changes which the General Electric transistor exhibited, the type 1729 showed less change with temperature. Figures 8, 9, and 10 indicate the change in static characteristics that takes place when the temperature is changed from -47°C to +90°C. It is believed that some hysteresis effect is present which may explain the lack of consistency in the change with temperature. The readings were first taken as the temperature was raised from room temperature to +90°C. Then the transistor was cooled from room temperature to -47°C. It is believed that the transistor should first have been raised to a temperature of +90°C and then readings taken as the temperature was progressively lowered to -47°C.

In general, the current gain seems to increase as the temperature is increased, and the curves tend to maintain approximately the same slope but shift laterally or vertically.

It appears that the type 1729 transistor can be used at temperatures ranging from -47°C to about 80°C providing that the collector dissipation is kept fairly low.

In a stability test in which a transistor was operated at an emitter current of 2 milliamperes and a collector current of 4 milliamperes for a period of seven hours no material change was observed in the static characteristics.

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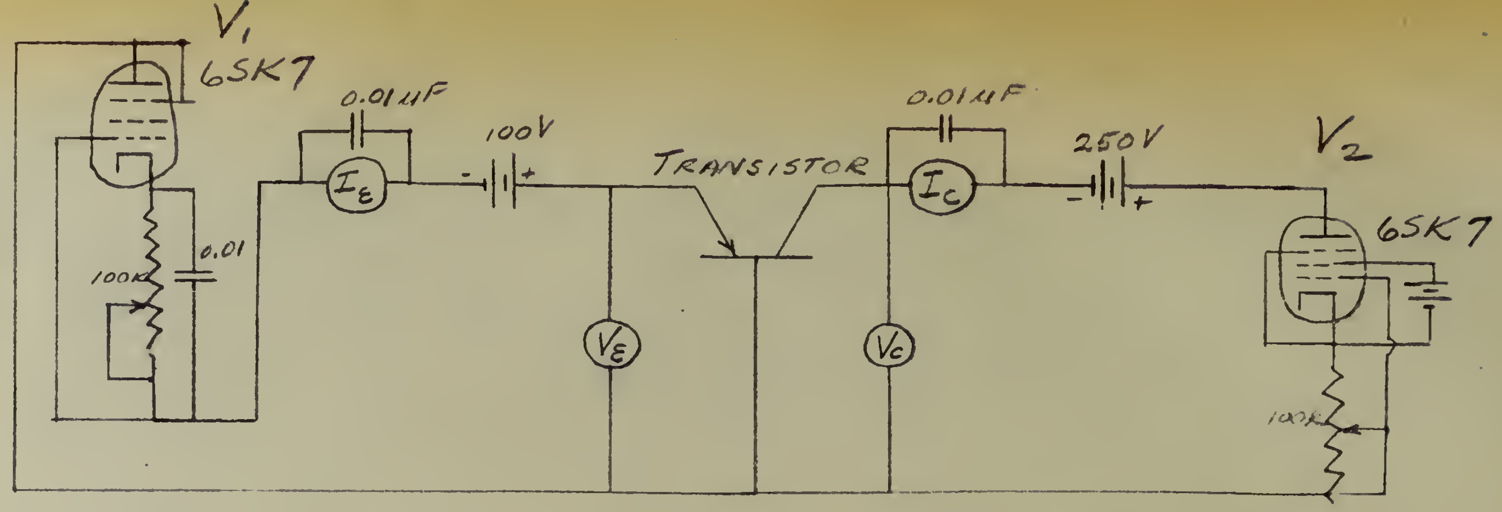
Appendix I

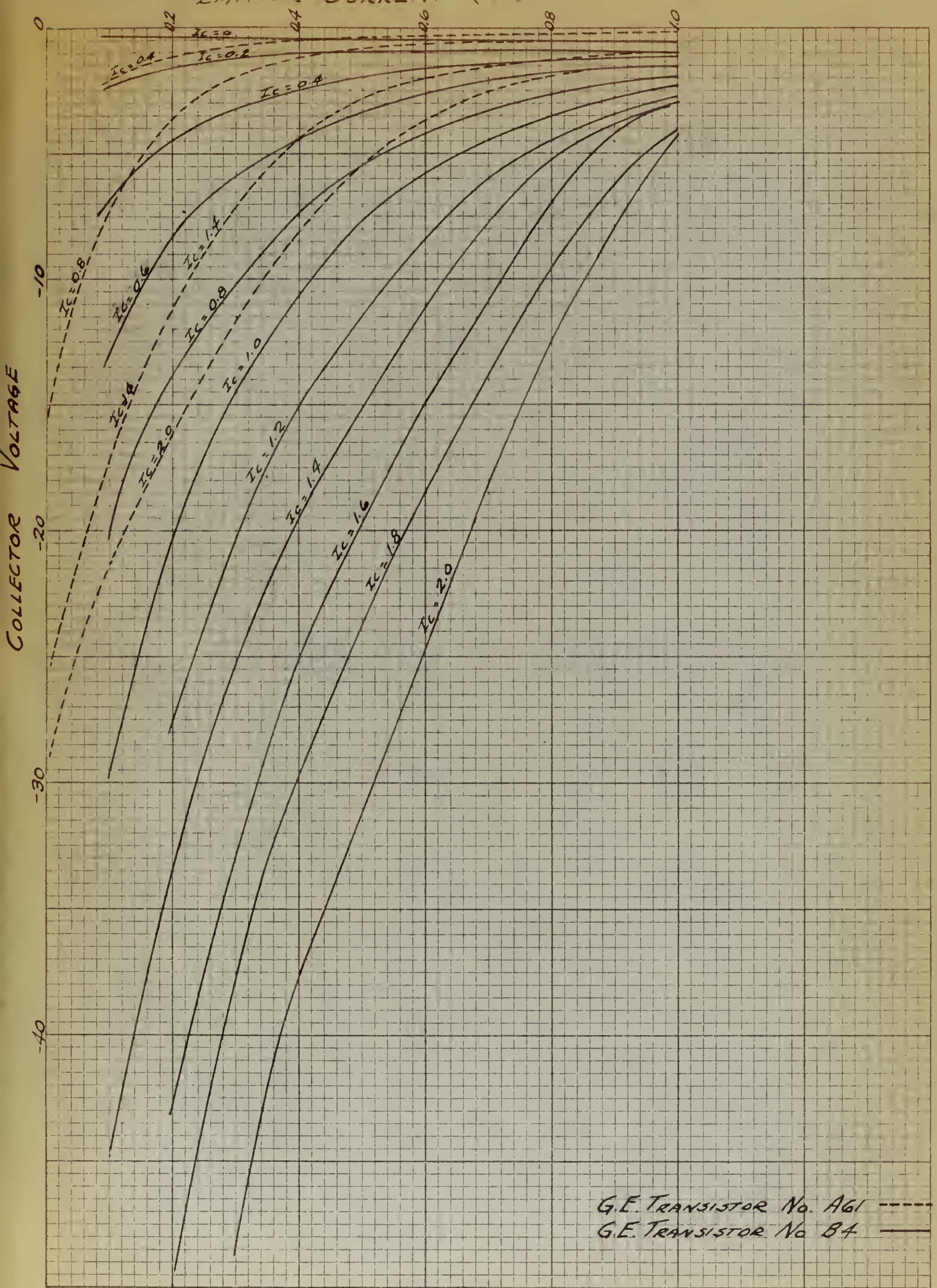



CIRCUIT FOR MEASURING STATIC CHARACTERISTICS OF TRANSISTORS

NOTE:

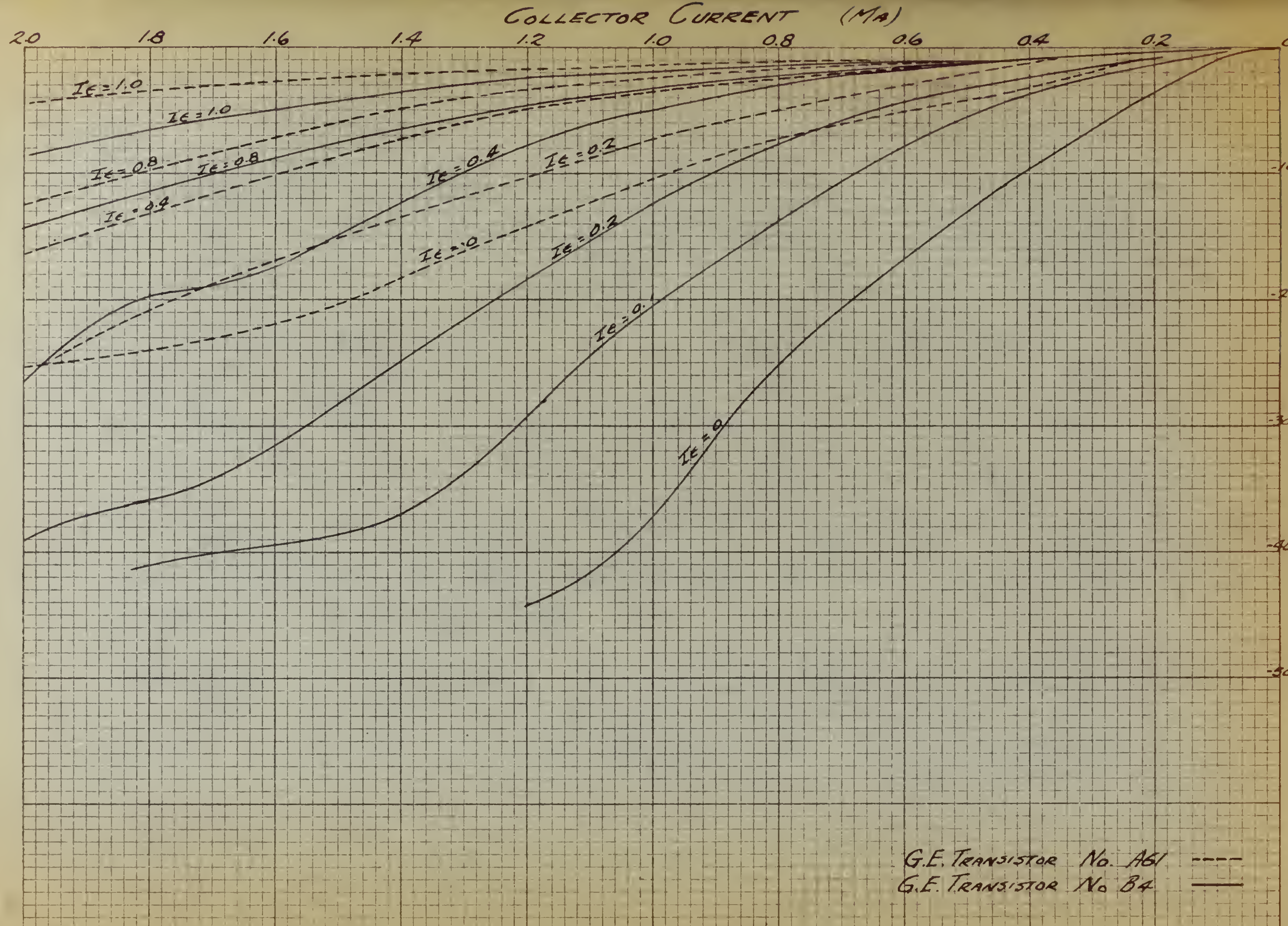
WHEN MEASURING STATIC CHARACTERISTICS OF GENERAL ELECTRIC TYPE G11 TRANSISTORS, $V_1$ AND $V_2$ WERE REPLACED WITH 6SJ7 TUBES AND 1000 OHM CURRENT LIMITING RESISTORS WERE USED IN SERIES WITH THE 100K OHM CATHODE BIAS POTENTIOMETERS IN ORDER TO PREVENT $I_E$ AND $I_C$ FROM EXCEEDING ONE AND TWO MILLIAMPERES RESPECTIVELY.

FOR MEASURING CHARACTERISTICS OF BELL LABORATORIES TRANSISTORS THE ABOVE CIRCUIT WAS USED WITHOUT MODIFICATION



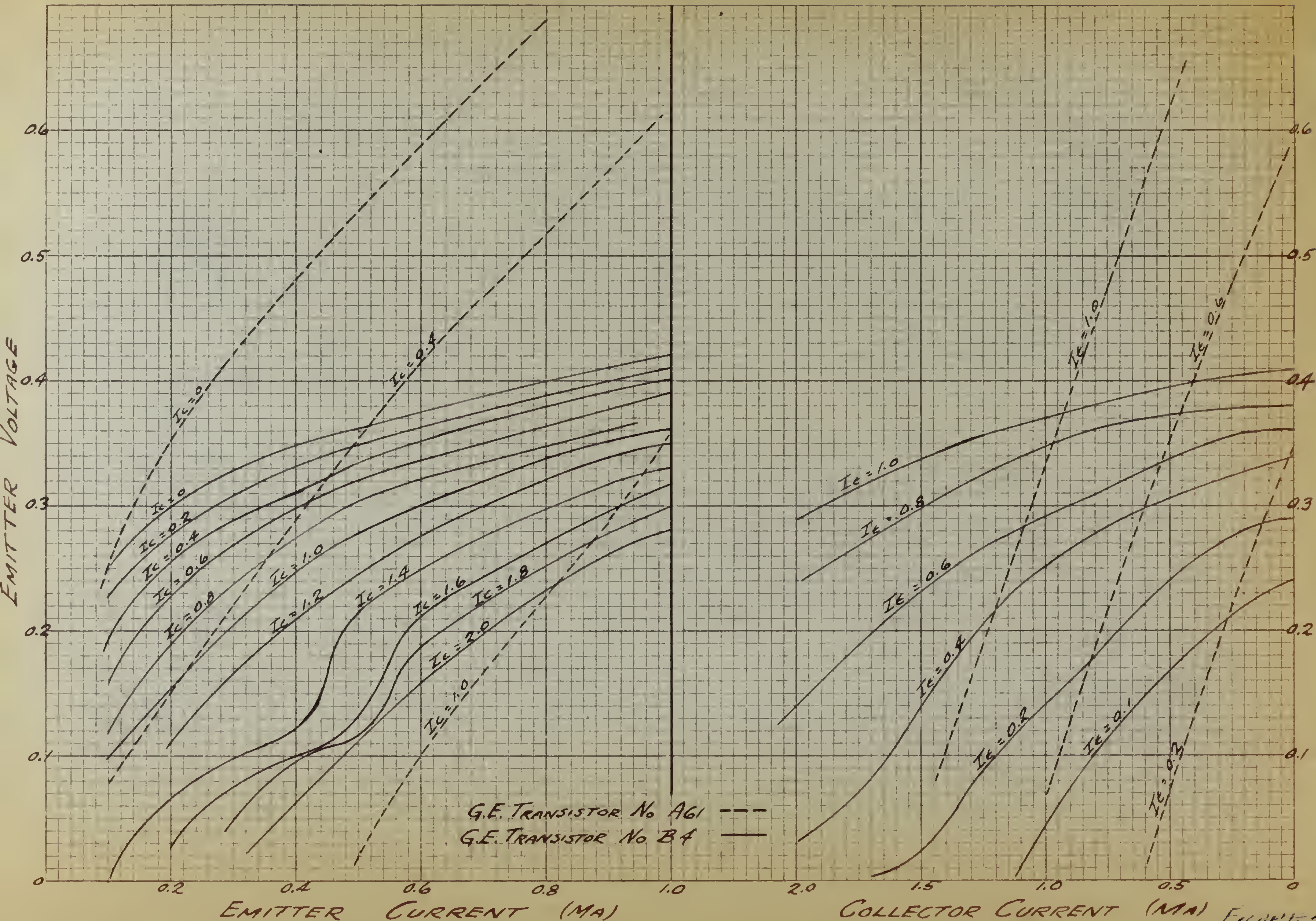
Collector Voltage
0
-10
-20
-30
-40
0.2
0.4
0.6
0.8
1.0
Ic = 0
Ic = 0.2
Ic = 0.4
Ic = 0.6
Ic = 0.8
Ic = 1.0
Ic = 1.2
Ic = 1.4
Ic = 1.6
Ic = 1.8
Ic = 2.0
G.E. Transistor No. A61
G.E. Transistor No B4


Figure 2

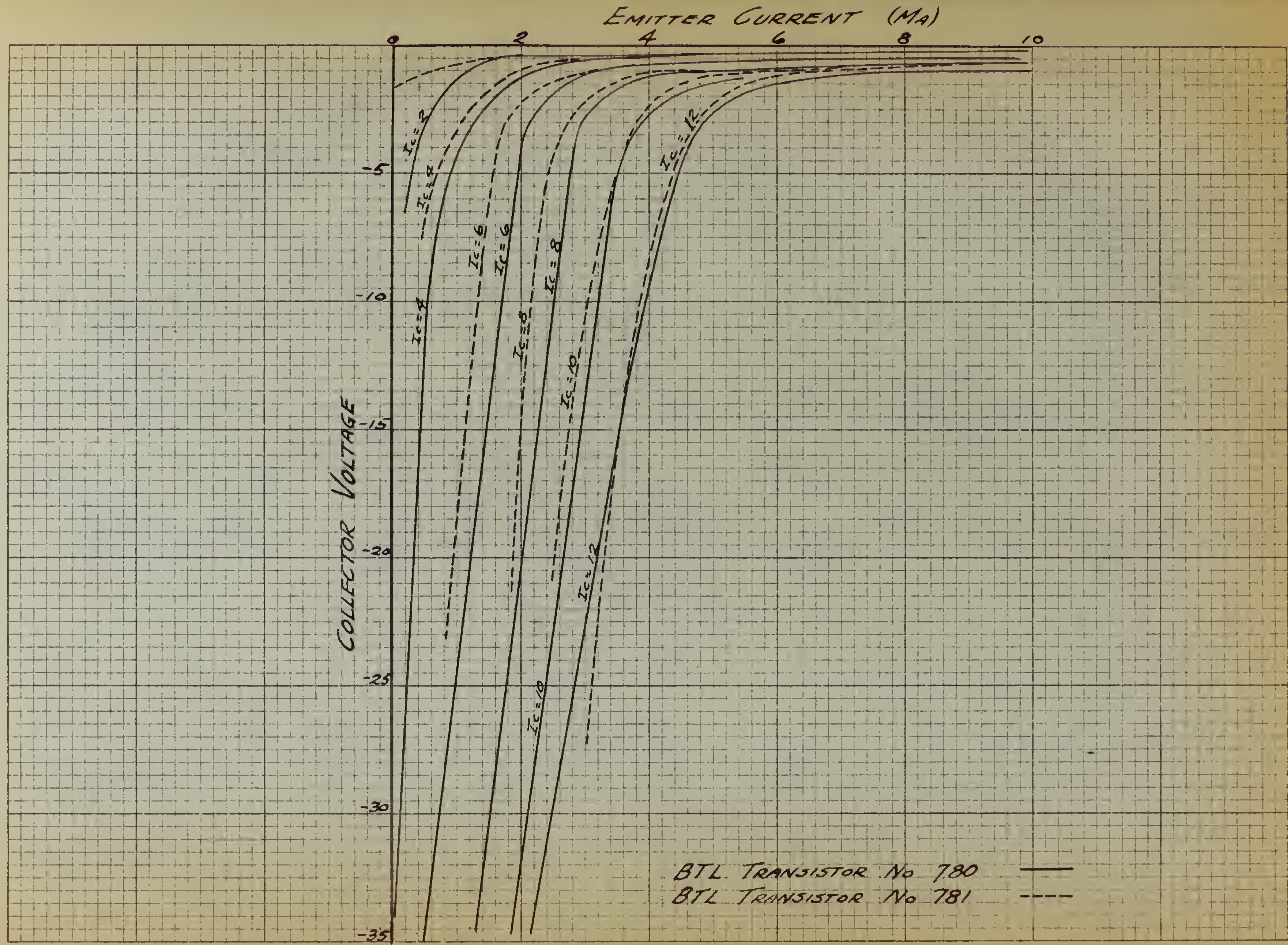


COLLECTOR CURRENT (MA)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
-10
-20
-30
-40
-50
Ie = 1.0
Ie = 1.0
Ie = 0.8
Ie = 0.8
Ie = 0.4
Ie = 0.4
Ie = 0.2
Ie = 0.2
Ie = 0
Ie = 0.1
Ie = 0
G.E. TRANSISTOR No. A61 ----
G.E. TRANSISTOR No B4 ——

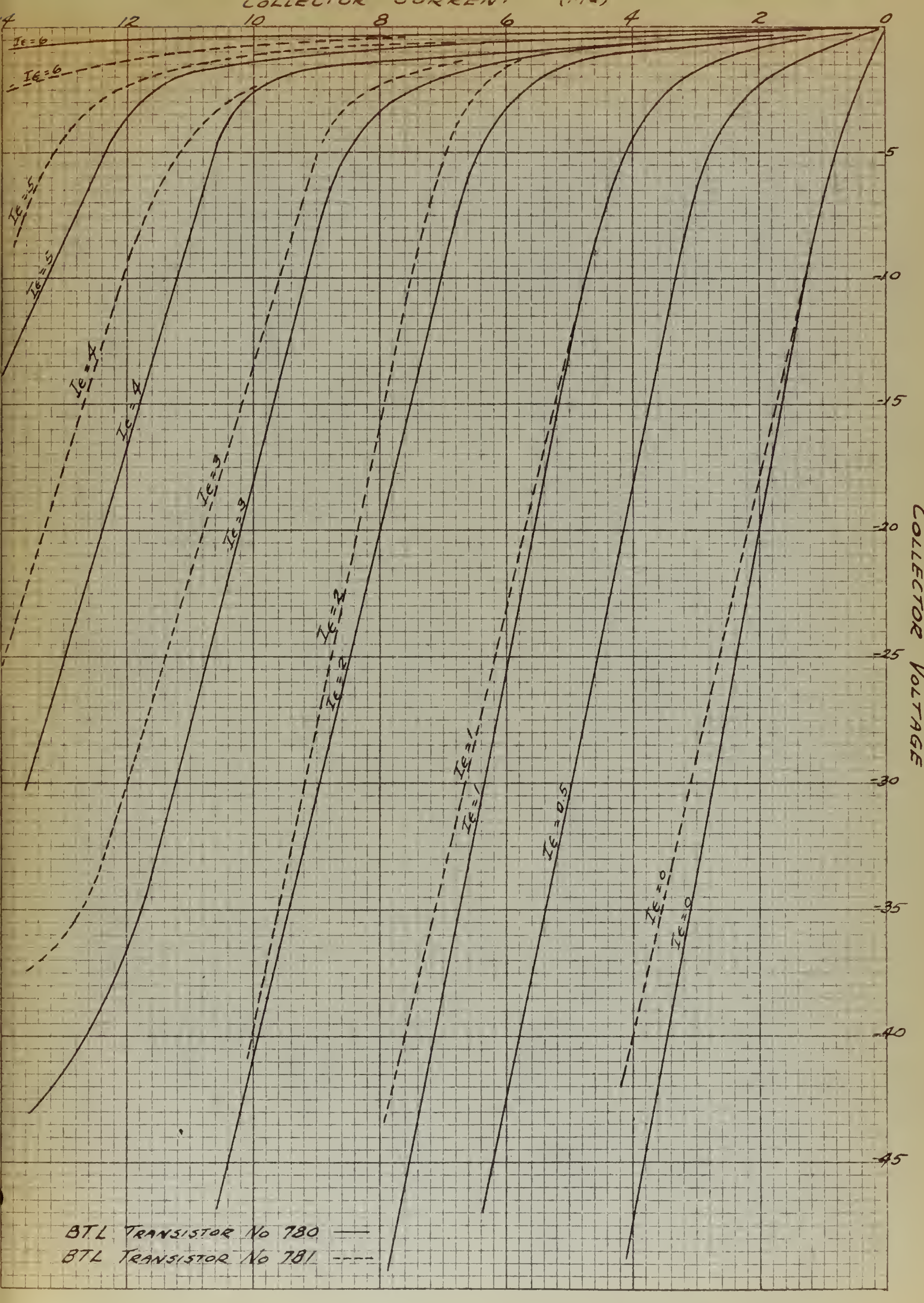

FIGURE 3


EMITTER VOLTAGE
EMITTER CURRENT (MA)
COLLECTOR CURRENT (MA)
G.E. TRANSISTOR No A61
G.E. TRANSISTOR No B4
Ic = 0
Ic = 0.2
Ic = 0.4
Ic = 0.6
Ic = 0.8
Ic = 1.0
Ic = 1.2
Ic = 1.4
Ic = 1.6
Ic = 1.8
Ic = 2.0

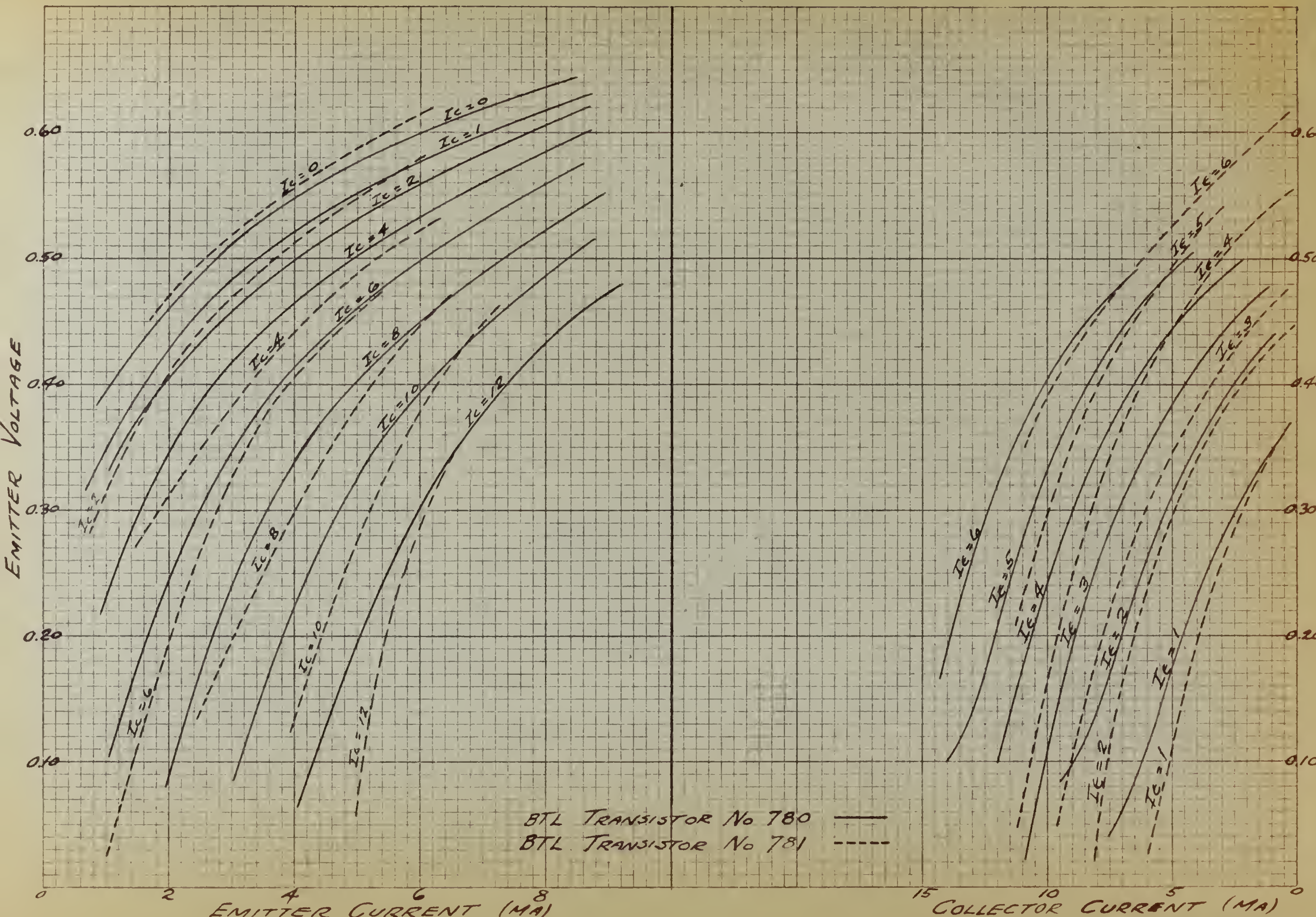
FIGURE



EMITTER CURRENT (MA)
0
2
4
6
8
10
COLLECTOR VOLTAGE
-5
-10
-15
-20
-25
-30
-35
Ic=2
Ic=4
Ic=6
Ic=8
Ic=10
Ic=12
BTL TRANSISTOR No 780
BTL TRANSISTOR No 781

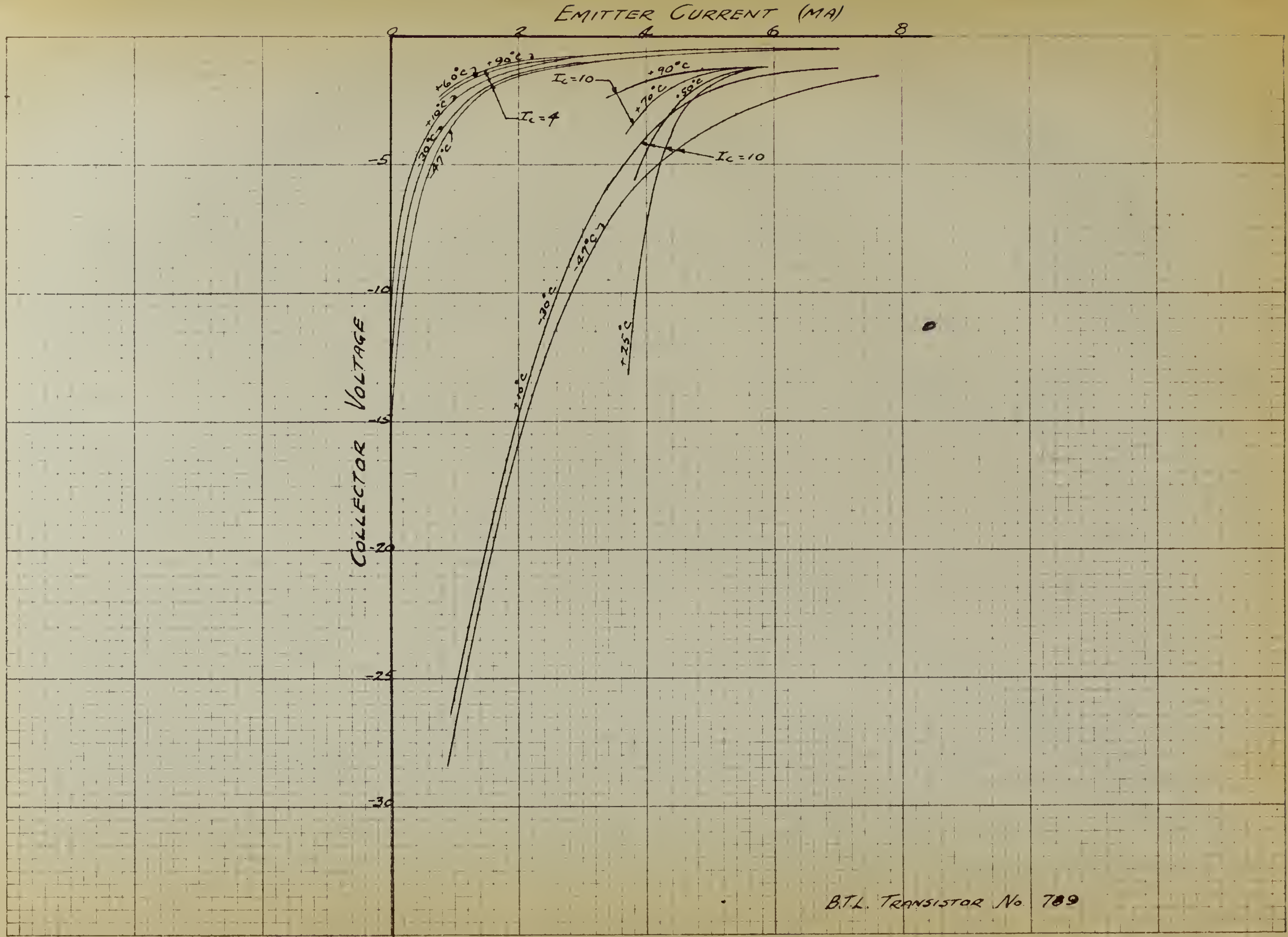


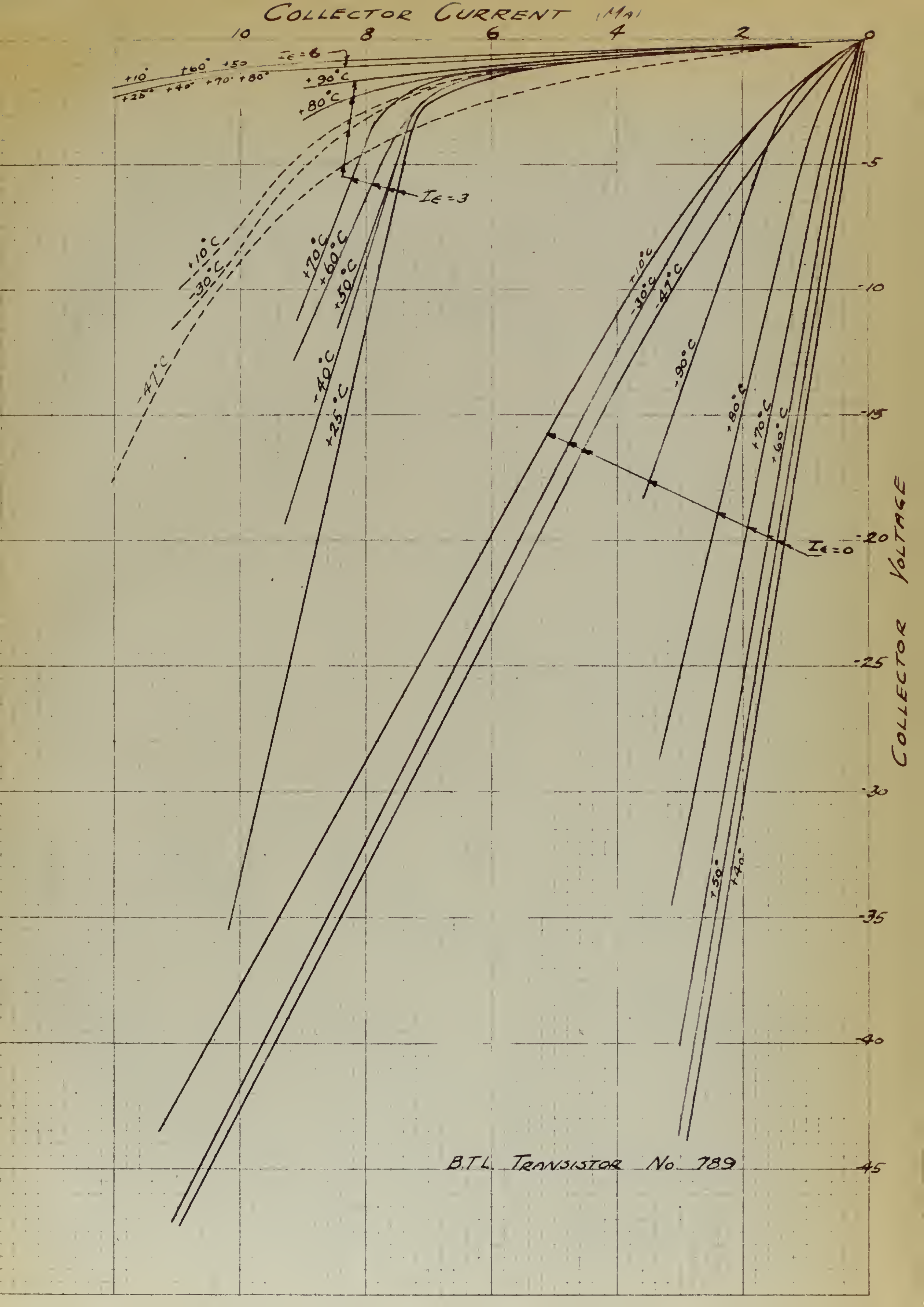
12
10
8
6
4
2
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
Ie=6
Ie=5
Ie=4
Ie=3
Ie=2
Ie=1
Ie=0.5
Ie=0
COLLECTOR VOLTAGE
BTL TRANSISTOR No 780 ——
BTL TRANSISTOR No 781 ----



EMITTER VOLTAGE
EMITTER CURRENT (MA)
COLLECTOR CURRENT (MA)
0.60
0.50
0.40
0.30
0.20
0.10
0
2
4
6
8
15
10
5
Ic=0
Ic=1
Ic=2
Ic=4
Ic=6
Ic=8
Ic=10
Ic=12
Ie=1
Ie=2
Ie=3
Ie=4
Ie=5
Ie=6
BTL TRANSISTOR No 780
BTL TRANSISTOR No 781


FIGURE 7


EMITTER CURRENT (MA)
0
2
4
6
8
COLLECTOR VOLTAGE
-5
-10
-15
-20
-25
-30
+60°C
+90°C
+10°C
-30°C
-47°C
$I_c = 4$
$I_c = 10$
+90°C
+70°C
+50°C
$I_c = 10$
-47°C
-30°C
+10°C
+25°C
B.T.L. TRANSISTOR No. 789



COLLECTOR CURRENT (MA)
10
8
6
4
2
0
COLLECTOR VOLTAGE
-5
-10
-15
-20
-25
-30
-35
-40
-45
$I_E = 6$
$I_E = 3$
$I_E = 0$
+10°
+60°
+50
+20°
+40°
+70°
+80°
+90°C
+80°C
+10°C
-30°C
-47°C
+70°C
+60°C
+50°C
-40°C
+25°C
+10°C
-30°C
-47°C
+90°C
+80°C
+70°C
+60°C
+50°
+40°
B.T.L. TRANSISTOR No. 789

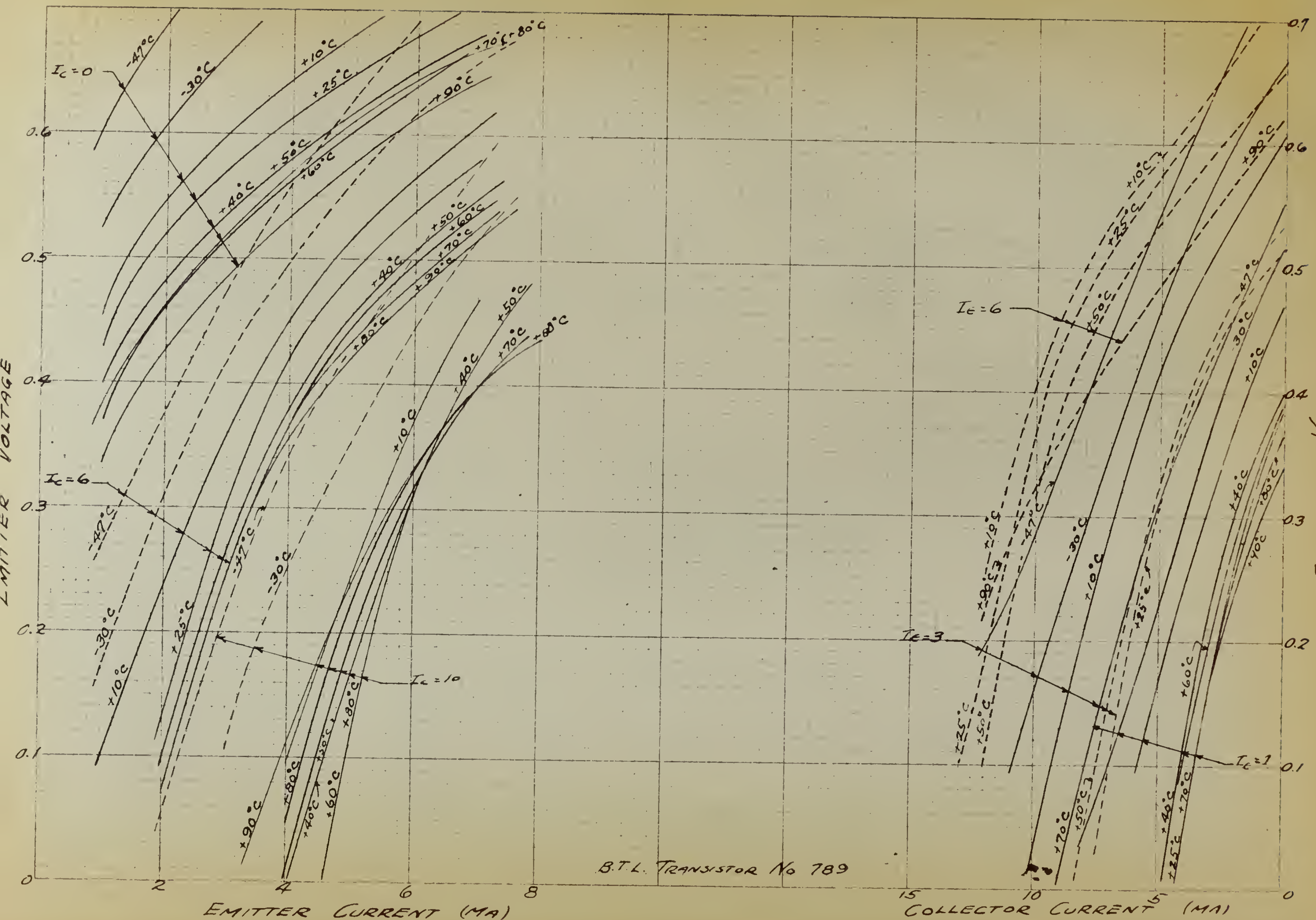
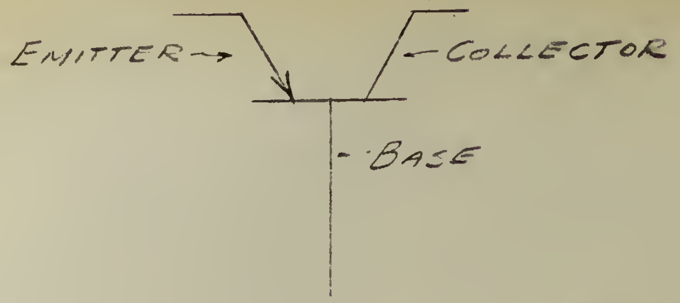
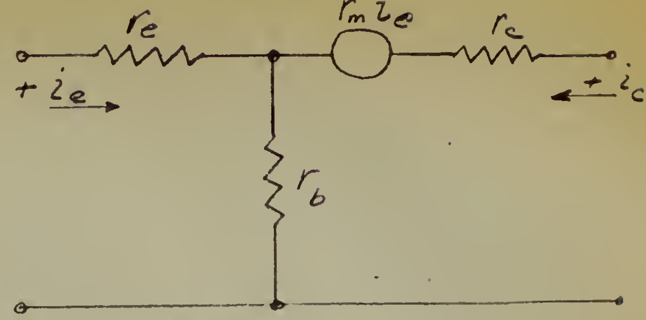

EMITTER VOLTAGE
EMITTER CURRENT (MA)
COLLECTOR CURRENT (MA)
B.T.L. TRANSISTOR No 789
$I_c=0$
$I_c=6$
$I_c=10$
$I_E=6$
$I_E=3$
$I_E=1$
-47°C
-30°C
+10°C
+25°C
+40°C
+50°C
+60°C
+70°C
+80°C
+90°C

FIGURE 10

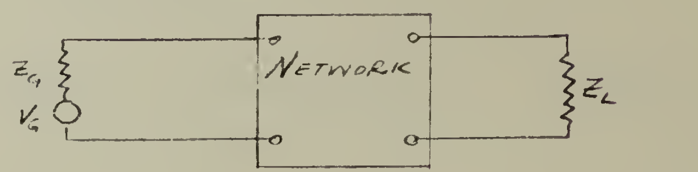



CIRCUIT SYMBOL FOR
TYPE A (POINT CONTACT) TRANSISTOR

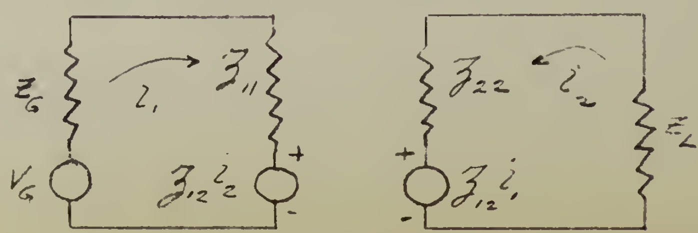



EQUIVALENT CIRCUIT
REPRESENTATION OF THE
TRANSISTOR

CIRCUIT




EQUIVALENT CIRCUIT




EQUATIONS

$$i_1(Z_g + Z_{11}) + i_2 Z_{12} = V_G$$
$$i_1 Z_{21} + i_2 (Z_{22} + Z_L) = 0$$

CIRCUIT DETERMINANT: $\Delta = (Z_{11} + Z_g)(Z_{22} + Z_L) - Z_{12} Z_{21}$

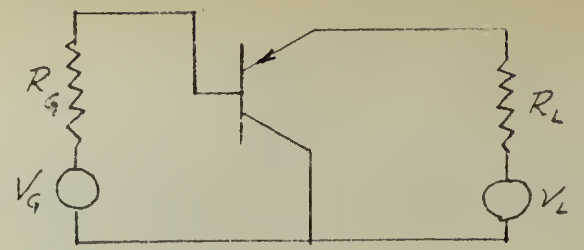
INPUT IMPEDANCE. $Z_{11} = Z_{11} - \dfrac{Z_{12} Z_{21}}{Z_{22} + Z_L}$

OUTPUT IMPEDANCE: $Z_{22} = Z_{22} - \dfrac{Z_{12} Z_{21}}{Z_{11} + Z_G}$

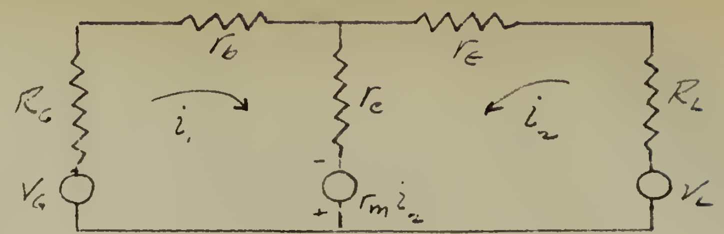
OPERATING POWER GAIN $G_0$: $= 4 R_G R_L \left| \dfrac{-Z_{21}}{\Delta} \right|^2$

INSERTION POWER GAIN $G_i$: $= \left| \dfrac{(Z_G + Z_L) Z_{21}}{\Delta} \right|$

CIRCUIT




EQUIVALENT CIRCUIT




EQUATIONS:

$$i_1(R_G + r_b + r_c) + i_2(r_c - r_m) = V_G$$

$$i_1 r_c + i_2(R_L + r_e + r_c - r_m) = V_L$$

CIRCUIT DETERMINANT: $\Delta = (R_G + r_b + r_c)(R_L + r_e + r_c - r_m) + r_c(r_m - r_c)$

$> 0$ FOR STABILITY

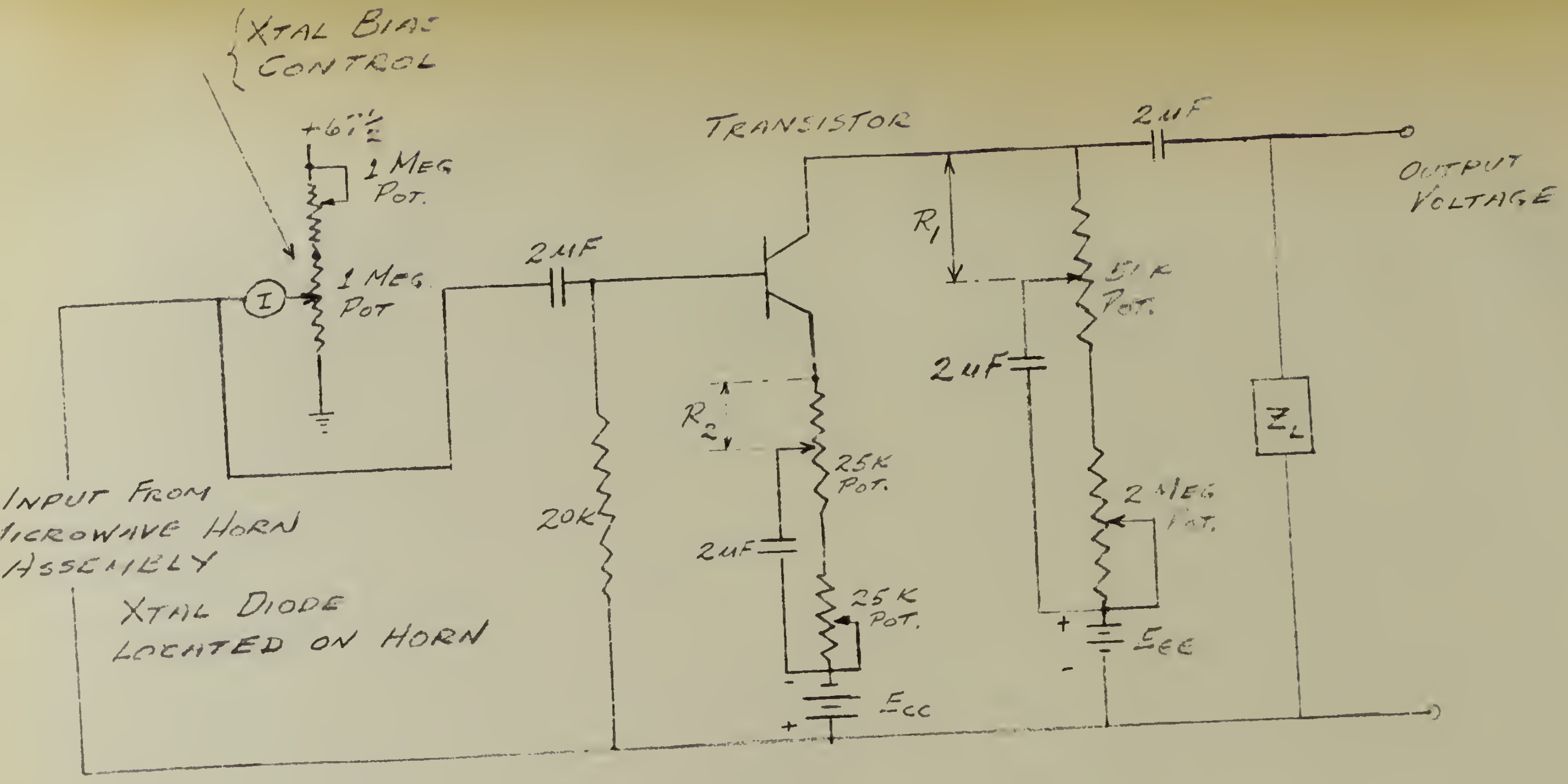
INPUT IMPEDANCE: $R_{11} = r_b + r_c + \dfrac{r_c(r_m - r_c)}{R_L + r_e + r_c - r_m}$

OUTPUT IMPEDANCE: $R_{22} = r_e + r_c - r_m + \dfrac{r_c(r_m - r_c)}{R_G + r_b + r_c}$

OPERATING GAIN: $G_F = 4 R_G R_L \left(\dfrac{-r_c}{\Delta}\right)^2$

BACKWARD OPERATING GAIN: $G_R = 4 R_G R_L \left(\dfrac{-r_c + r_m}{\Delta}\right)^2$

# SYNOPSIS OF GROUNDED COLLECTOR AMPLIFIER




GROUNDED-COLLECTOR TRANSISTOR AMPLIFIER

## CIRCUIT PARAMETERS

$$\left.\begin{aligned}
R_{11} &= Z_{11} = r_b + r_E \\
R_{21} &= Z_{21} = r_b + r_m \\
R_{12} &= Z_{12} = r_b \\
R_{22} &= Z_{22} = r_b + r_c + R_L
\end{aligned}\right\} \quad \text{FOR GROUNDED BASE OPERATION}$$

FROM STATIC CHARACTERISTICS

$$\left.\begin{aligned}
R_{11} &= 150 \text{ OHMS} \\
R_{12} &= 50 \text{ OHMS} \\
R_{21} &= 24000 \text{ OHMS} \\
R_{22} &= 12000 \text{ OHMS}
\end{aligned}\right\} \quad \text{FOR } I_E = 1 \text{ mA}, \; V_C = 30 \text{ VOLTS}$$

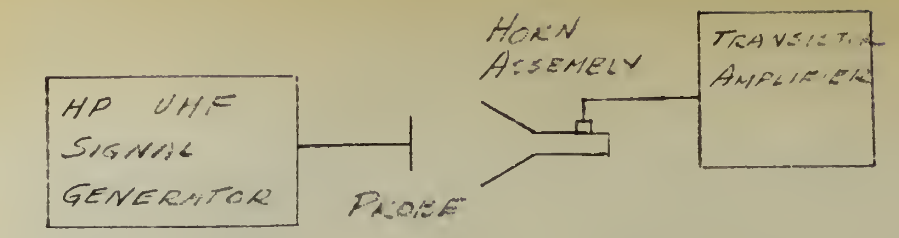
THEN

$$r_b = R_{12} = 50 \text{ OHMS}$$

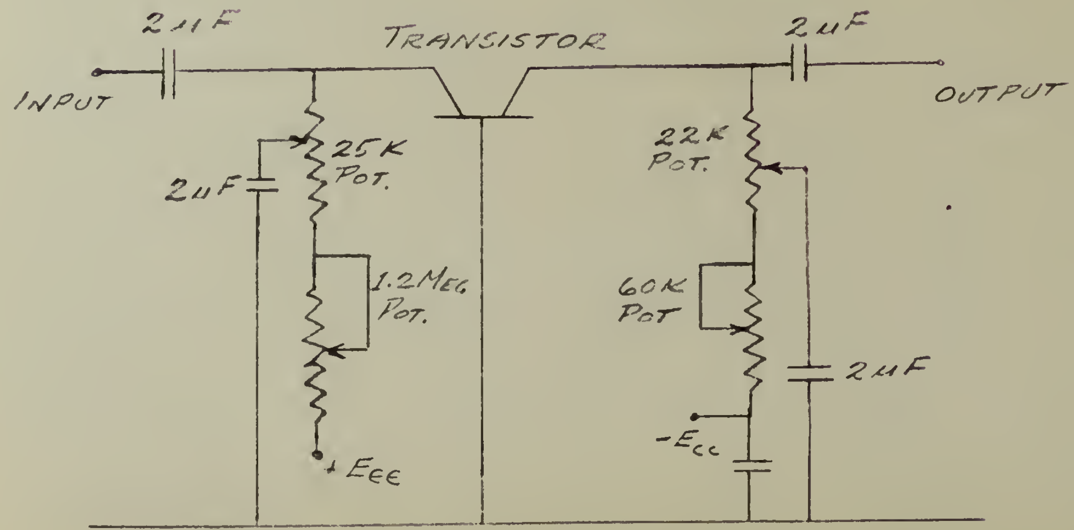
$$r_e = R_{11} - R_b = 150 - 50 = 100 \text{ OHMS}$$

$$r_m = R_{21} - r_b = 24000 - 50 = 23950$$

$$r_c = R_{22} - r_b = 12000 - 50 = 11950$$




TRANSISTOR AMPLIFIER TEST SET-UP




GROUNDED - BASE TRANSISTOR AMPLIFIER

NOTE:

THE BIAS VOLTAGES, $E_{CC}$ AND $E_{EE}$ ARE INTENDED TO BE THE SAME AS FOR PRECEEDING STAGE

# GROUNDED-COLLECTOR AMPLIFIER DATA

| LOAD IMPEDANCE Ω | INPUT IMPEDANCE FIRST RUN Ω | INPUT IMPEDANCE RE-RUN Ω | INPUT VOLTAGE | OUTPUT VOLTAGE | GAIN | RISE TIME μs | $R_2$ Ω | REMARKS |
|---|---|---|---|---|---|---|---|---|
| 500 | 2000 | 680 | 0.58 | 0.48 | 0.83 | 0.1 | 2K | |
| 400 | 2000 | | 0.58 | 0.44 | 0.76 | 0.1 | 2K | |
| 300 | 1500 | | 0.58 | 0.41 | 0.71 | 0.6 | 2K | |
| 200 | 1000 | 560 | 0.55 | 0.36 | 0.62 | 0.3 | 2K | |
| 100 | 550 | 450 | 0.52 | 0.26 | 0.50 | 0.2 | 2K | |
| 1000 | 4400 | 1100 | 0.09 | 0.08 | 0.89 | 0.2 | 2K | |
| 100 | ABOVE 1 MEG. | 500 | 0.07 | .04 | 0.57 | 0.2 | 1K | [illegible] FOR |
| 200 | " | 450 | 0.063 | .045 | 0.71 | 0.2 | 1K | |
| 300 | " | 750 | 0.063 | 0.44 | 0.70 | 0.2 | 1K | ALL |
| 400 | " | 750 | 0.062 | 0.05 | 0.81 | 0.2 | 1K | |
| 500 | " | 850 | 0.059 | 0.046 | 0.79 | 0.2 | 1K | LOAD |
| 1000 | 4600 | 860 | 0.055 | 0.045 | 0.37 | 0.2 | 1K | |
| 2000 | 2000 | 1100 | 0.055 | 0.053 | 0.96 | 0.2 | 1K | TERMINAL |
| 4000 | 1200 | 1000 | 0.055 | 0.053 | 0.96 | 0.2 | 1K | |
| [illegible] | — | 400 | — | — | | 0.2 | 0 | [illegible] |
| [illegible] | ABOVE 1 MEG | 400 | 0.078 | 0.056 | 0.74 | 0.2 | 0 | |
| [illegible] | " | 450 | 0.055 | 0.048 | 0.87 | 0.2 | 0 | |
| [illegible] | " | 450 | 0.056 | 0.048 | 0.86 | 0.2 | 0 | |
| [illegible] | " | | 0.055 | 0.052 | 0.95 | 0.2 | 0 | |
| [illegible] | " | 450 | 0.053 | 0.050 | 0.94 | 0.2 | 0 | |
| 2000 | | 1850 | 0.05 | 0.04 | 0.80 | 0.2 | 11K | |

BELL LABORATORIES TYPE 1729

IN ALL TESTS $R_1$ WAS SET AT 50K AND THE FOLLOWING OPERATING CONDITIONS WERE MAINTAINED.

$I_c$ = 4.3 MILLIAMPERES

$I_e$ = 0.7 "

INPUT PULSE WIDTH 2 MICROSECONDS

Vessell

Report of the industrial engineering tour at the Federal Telecommunication Laboratories, Nutley, New Jersey.

Thesis
V43
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28819
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